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Study 688

The Effectiveness of A-1 Bombing Attacks on Bridges (U)

CENTER FOR NAVAL ANALYSES
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28 APR 1965

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From: Chief of Naval Operations
To: Distribution List

Subj: Operations Evaluation Group Study No. 688; forwarding of (U)

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1. Enclosure (1), prepared by the Operations Evaluation Group of the Center for Naval Analyses, is forwarded for information and retention. This study represents the best opinion of OEG at the time of issue.

2. This study analyzes the effectiveness of various A-1 aircraft loads against girder and truss bridges to arrive at weapon recommendations and force requirements for use in operational planning. The optimum basic load recommended is 8 Mk 82 500-pound bombs, regardless of bridge type.

3. The Chief of Naval Operations approves this study for use in operational planning and weapons selection.

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OPERATIONS EVALUATION GROUP

STUDY NO. 688

THE EFFECTIVENESS OF A-1 BOMBING ATTACKS ON BRIDGES (U)

By L.R. Heselton, Jr.

Approved by: W.G. Leight W.G. Leight, Operations Evaluation Group
For The Director

28 April 1965

This study represents the view of the Operations Evaluation Group at the time of issue. It does not necessarily reflect the official opinion of the Chief of Naval Operations except to the extent indicated in the forwarding letter. It includes information of an operational rather than a technical nature, and should be made available only to those authorized to receive such information.

Enclosure (1) to
CNO ltr ser 03P03
Dated 28 April 1965

Prepared by the
OPERATIONS EVALUATION GROUP
Center for Naval Analyses

[redacted]

ABSTRACT

This study determines the effectiveness of various A-1 aircraft payloads against bridges. The optimum load, regardless of bridge type, consists of eight-500 pound bombs plus additional ordnance as permitted by radius, loading time, and weight considerations. The effects of different intervalometer settings and approach angles are also analyzed: effectiveness is reduced if long intervalometer settings are used, but is insensitive to approach angle if the optimum setting is used. Data for adjusting the effectiveness estimates to reflect variations in bridge size and delivery accuracy are also provided.

[redacted]

INTRODUCTION

This study compares the effectiveness of various bombs delivered by the A-1 H/J aircraft against girder and truss bridges to arrive at weapon recommendations and force requirements for use in operational planning. It extends the data of previous analyses by reflecting characteristics peculiar to the A-1 and by determining the effectiveness of sticks of bombs rather than of repeated individual bomb drops.

[redacted]

SUMMARY AND CONCLUSIONS

- The basic payload recommended for attacks on both girder and truss bridges is eight Mk 82 (500 pound) bombs. Carriage of additional ordnance on stations not required for external fuel will increase effectiveness slightly, hence is recommended. However, since Mk 81 (250 pound) bombs are ineffective against truss bridges, adding them to the basic payload is not worthwhile when the target is a truss bridge.
- Intervalometer setting should be 5 releases per second if pairs are selected and 10 releases per second for single bombs in train.
- Effectiveness is largely insensitive to the direction of the attack relative to the bridge axis if optimum intervalometer setting is used.
- Sortie requirements for representative payloads are summarized in table I. Data for additional loadings, bridges of different dimensions, and different delivery accuracy is given in the text.

TABLE I

EXPECTED NUMBER OF SORTIES TO DROP AT LEAST ONE SPAN OF A 300 X 20 FOOT BRIDGE

	Girder Bridge		Truss Bridge	
	One Pass	Two Passes	One Pass	Two Passes
8 Mk 82, (500#) 2 Mk 84 (2000#)	6.6	5.6	11.5	10.0
8 Mk 82, (500#) 2 Mk 83 (1000#)	6.6	5.6	12.4	11.0
8 Mk 82, (500#) 1 Mk 84 (2000#)	7.0	6.4	13.3	12.2
8 Mk 82, (500#)	7.6	6.4	15.4	13.9
12 Mk 81, (250#)	8.3	7.0	Weapon Unsuitable	

[redacted]

DELIVERY TACTICS, DAMAGE CRITERIA AND OTHER INPUTS

The basic delivery tactic assumed is the 30° glide with release at 2200 feet altitude specified in reference (a). On the basis of reference (b), average combat accuracy for this maneuver is estimated as a CEP of 160 feet (REP = 110 feet, DEP = 70 feet). This estimate has been agreed to by a Joint Working Party composed of representatives of all 3 services (reference (c)). The use of other delivery tactics and the effect of different accuracies is discussed in appendix C.

The damage criterion is collapse of at least one span of the bridge. Based on extensive World War II data, discussed in appendix A, the probability that a hit will collapse a span is estimated to be that summarized in table II.

TABLE II
PROBABILITY THAT A HIT WILL COLLAPSE A SPAN

Bridge Type	Bomb Size			
	250 pounds*	500 pounds	1000 pounds	2000 pounds
Girder	0.3	0.5	0.6	0.6
Truss	Inadequate	0.2	0.3	0.4

*Estimated: No operational data.

Since the basic operational data on span collapse probabilities includes the effect of reliability and was in any case rounded off to one significant figure, no further discount for bomb reliability was taken. Fuzing recommendations are given in reference (d). Instantaneous fuzing is recommended for attack on through type girder bridges and slight delay fuzing (0.01 sec or less) for other types.

The relationship between bomb spacing in a stick and intervalometer setting, and other related details of the A-1 bomb release system are discussed in appendix B. The basic settings recommended are 5 releases per second for "pairs" and 10 releases per second for singles; these produce a spacing of approximately 40 feet between pairs of bombs or 20 feet between single bombs in train, neglecting ballistic dispersion. Ballistic dispersion is assumed to be 10.5 feet normal to the trajectory.

Sensitivity to variations in these parameters is analyzed in appendix C.

References (e) and (f) were used to compute effectiveness.

[redacted]

RESULTS AND DISCUSSION

The effectiveness of various bombs for attack against girder and truss bridges is presented in tables III and IV. These tables list the probability of collapse of at least one span when the weapons indicated are dropped in a single pass. The expected number of sorties required is given for all weapons delivered on a single pass and also for weapons delivered on two separate passes. Multiple passes improve the effectiveness from 10-20 percent depending on the total bomb load. However, aircraft vulnerability considerations often will require that all ordnance be dropped on a single pass. If bombs are released from both inner and outer wing stations, the Inner Station Release Switch (pickle) should be closed just after the Outer Station Release Switch to more nearly center the inner station pattern on the target, the sight setting being such that the center of the stick from the outer wing stations is placed on the center of the bridge.

Approximate maximum radii are given for each of the weapons loads listed. These radii are for comparative purposes only and should not be used for detailed sortie planning. They are based on full internal fuel plus 300 gallon external tanks on each available station. The values were calculated from the data given in reference (g) with a Hi-Hi profile and a fuel allowance of 700 pounds for combat and reserve.

The basic recommended weapons loading for attacks against either girder or truss bridges is eight Mk 82 (500 pound) GP bombs. Depending on the range to target and the external fuel requirements, additional bombs should be added to this basic load. For example, addition of two Mk 83 (1000 pound) GP bombs to the basic Mk 82 load increases sortie effectiveness 15-25 percent, but decreases maximum radius by more than 500 miles. If Mk 82 GP are not available, substitution of 12 Mk 81 GP for the 8 Mk 82 GP will cause only about 10 percent degradation in effectiveness against girder bridges, but the Mk 81 bombs are not suitable against truss bridges.

High drag bombs, where compatible, may be substituted for the low drag bombs listed with essentially the same effectiveness.

The probabilities of collapse in tables III and IV were calculated (by methods in appendix D) for a 30° glide delivery along the axis of a bridge 300 feet long and 20 feet wide, using a stick spacing of 40 feet between bombs released in pairs (or 20 feet if released singly in train). Detailed discussion of the effect of changes in these parameters is given in appendix C. As would be expected, sortie effectiveness is affected greatly by delivery accuracy and target size. A degradation of 10 feet in DEP (i.e., from 70 feet to 80 feet) would require 10 percent more sorties, while a bridge twice as long or twice as wide would require 30-40 percent fewer sorties. The effectiveness of a sortie is essentially the same whether the stick is dropped by pairs or singly in train, due to the large distance between opposite stations on the A-1. For a stick length of 100-200 feet, effectiveness is relatively insensitive to the approach

[redacted]

[redacted]

TABLE III

SORTIE EFFECTIVENESS AGAINST GIRDER BRIDGE(20 X 300 FEET)

Weapons	Probability of Success(1)	Expected Sorties Required With Weapons Released On One Pass	Two Passes	Approx. Radius(3)
8 Mk 82 GP/3 Mk 83/84 GP(2)	.159	6.3	5.1	210/130
12 Mk 81 GP/3 Mk 83/84 GP	.152	6.6	5.4	230/170
8 Mk 82 GP/2 Mk 83/84 GP	.152	6.6	5.6	480/360
12 Mk 81 GP/2 Mk 83/84 GP	.142	7.0	6.0	550/450
8 Mk 82 GP/1 Mk 83/84 GP	.142	7.0	6.4	770/690
8 Mk 82 GP	.132	7.6	6.4	1020
12 Mk 81 GP/1 Mk 83/84 GP	.130	7.7	6.9	840/770
12 Mk 81 GP	.120	8.3	7.0	1110
4 Mk 82 GP	.082	12.2	---	1140
3 Mk 83/84 GP	.072	13.9	12.4	290/230
2 Mk 83/84 GP	.054	18.5	17.5	660/590
1 Mk 83/84 GP	.029	33.5	---	1020/970

Notes: (1) Probability of collapse of at least one span when weapons indicated are delivered on a single pass.

(2) Mk 83 GP and Mk 84 GP have essentially same effectiveness against girder bridges.

(3) Where two values given, larger is for Mk 83 GP load, lesser for Mk 84 GP.

[redacted]

[redacted]

TABLE IV

SORTIE EFFECTIVENESS AGAINST TRUSS BRIDGE (20 X300 FEET)

Weapons[1]	Probability of Success[2]	Expected Sorties Required With Weapons Released On One Pass	Two Passes	Approx. Radius
8 Mk 82 GP/3 Mk 84 GP	.097	10.3	8.8	130
8 Mk 82 GP/3 Mk 83 GP	.090	11.1	9.7	210
8 Mk 82 GP/2 Mk 84 GP	.087	11.5	10.0	400
8 Mk 82 GP/2 Mk 83 GP	.081	12.4	11.0	500
8 Mk 82 GP/1 Mk 84 GP	.075	13.3	12.2	690
8 Mk 82 GP/1 Mk 83 GP	.072	13.9	12.7	770
8 Mk 82 GP	.065	15.4	13.9	1020
3 Mk 84 GP	.051	19.6	18.2	230
3 Mk 83 GP	.040	25.0	23.2	290
2 Mk 84 GP	.037	27.0	26.3	590
4 Mk 82 GP	.036	27.8	----	1140
2 Mk 83 GP	.028	35.7	33.3	660
1 Mk 84 GP	.019	52.6	----	970
1 Mk 83 GP	.015	66.7	----	1020

Notes: (1) Mk 81 GP not effective against truss bridges.

(2) Probability of collapse of at least one span when weapons indicated are delivered on a single pass.

[redacted]

angle, which may be chosen for tactical considerations rather than for maximum effectiveness. For attack along the bridge axis, effectiveness varies only slightly for stick lengths from 0-300 feet, and all bombs may be dropped in salvo with only slight degradation. However, for attacks off the axis, effectiveness drops markedly for sticks less than 100 feet or greater than 200 feet. For example, a salvo release at 90° is only 70 percent as effective as a 180 foot stick.

The tabulated values for expected sorties required are simply the reciprocals of the effectiveness of a single sortie (probability of collapse of at least one span per sortie). This means that if each of a large number of identical bridges are to be attacked until a span has been collapsed on each bridge, the number of sorties required may be anticipated to be the number of bridges times the tabulated number of expected sorties required per bridge. The values for 2 passes were derived by considering that, for a mixed load, the wing load would be dropped on one pass and the other bombs on a second pass. For a load consisting of one type bomb, half would be dropped on each pass.

Applications to Attack Planning

Attacks on bridges should normally take place only to support a comprehensive and carefully-planned interdiction program because piecemeal attacks on transportation have only local and short term effects. Reference (h) outlines the principles involved in developing a feasible and suitable interdiction campaign and reference (i) is an example of the type of over-all analysis which is required.

In planning bridge attacks, consideration must be given to enemy repair capabilities. Reference (h) indicates that key bridges in Korea were repaired in an average of 2 days, and were seldom unusable for as long as 6 to 7 days. Table V, derived from reference (j), summarizes the average repair times demonstrated by the Germans in World War II. Data on continuous truss bridges have been omitted from table V because of the small sample involved.

Finally, the probability of success as a function of the number of sorties over the target must be considered. If "n" is the number of sorties assigned to a given target, and "P_n" is the probability that the target will have been destroyed by the time no more than "n" sorties have been flown against it, then

$$P_n = 1 - (1 - p_1)^n$$

where p_1 = single sortie probability of success.

For the weapon loadings considered in this study, if approximately the expected number of sorties required for destruction be assigned to a bridge, the over-all probability of success is about 63 percent. It may be desired to increase this probability; alternatively, the number of sorties may be determined by other considerations. Since the resulting probability of success may be of interest, table VI provides guidance for these situations.

[redacted]

[redacted]

TABLE V

GERMAN ELAPSED REPAIR TIMES IN WORLD WAR II

	Simple Girder		Continuous Girder		Simple Truss		Masonry Arch		All Bridges	
Spans Erected	Average Days	Number of Incidents	Average Days	Number of Incidents	Average Days	Number of Incidents	Average Days	Number of Incidents	Average Days	Number of Incidents
1	5.6	7	7.4	11	4.9	86	5.1	17	5.1	129
2	7.1	7	10.7	10	7.9	48	9.4	14	8.4	80
3	---	-	15.9	8	8.4	17	9.2	5	10.5	20
4	12.5	2	9.0	3	17.1	8	25	2	15.9	15
5	15.0	1	---	---	11.7	7	---	---	12.1	8
6	---	---	19.0	1	8.2	5	---	---	10.0	6
7	---	---	---	---	22.3	3	---	---	22.3	3

TABLE VI
SUCCESS PROBABILITY FOR VARIATIONS IN STRIKE SIZE

Probability of Success	20%	30%	40%	50%	60%	63%	70%	80%	90%
Fraction of Expected Sorties	0.2	0.35	0.5	0.7	0.9	1.0	1.2	1.6	2.3

For example, if 12 A-1, each carrying eight Mk 82, attack a truss bridge 20 feet wide and 300 feet long with one pass each, the number of aircraft is roughly 0.8 times the expected number given in table I and the resulting success probability is about 55 percent.

[redacted]

References:
(a) CNO "Naval Air Training and Operating Procedures Standardization Manual A-1 H/J" Unclassified 17 Mar 1964
(b) OEG Study 659 "Predicted Combat Accuracy of Conventional Air to Surface Weapons (U)" Secret 7 Nov 1963
(c) Joint Munitions Effectiveness Manual Delivery Accuracy Working Party Report #3 "Average Combat Accuracy of Conventional Weapons (U)" Confidential 11 Nov 1964
(d) NWIP 20-1, "Naval Weapons Selection-Aircraft (U)" Confidential 21 Apr 1961
(e) NAVWAG NIRM-12 "Usage Manual for a Computer Program to Compute the Effectiveness of Groups of Weapons Against Rectangular and Line Targets" Unclassified 21 Aug 1962
(f) OEG RC-46 "Weapon Pattern Effectiveness I OEG Computer Program 17-63P" Unclassified 1 Oct 1963
(g) NAVWEPS 01-04 ALF-1 "Flight Handbook AD-6, AD-7 Aircraft" Unclassified 1 Jan 1961
(h) OEG Study 552 "Factors Influencing the Interdiction of Land Transportion (U)" Confidential 23 Aug 1955
(i) OEG Study 674 "Interdiction in North Vietnam (C)" Secret 23 Apr 1964
(j) Lehigh University Bomb Damage Analysis Final Report Volume III Part 2 Phase IV "Bridges" Unclassified 20 Jun 1949

[redacted]

APPENDIX A

[redacted]

APPENDIX A

BRIDGE VULNERABILITY

The basic data for determining bridge vulnerability is found in bomb damage assessments for World War II. In reference (a) over 1300 incidents are analyzed where German and other records permitted identification of bomb size and degree of damage sustained. This analysis is summarized in table A-I.

TABLE A-1

FRACTION OF HITS COLLAPSING AT LEAST ONE BRIDGE SPAN

	500 pound Bomb		1000 pound Bomb		2000 pound Bomb	
Type of Bridge	Number of Hits	Fraction Collapsing	Number of Hits	Fraction Collapsing	Number of Hits	Fraction Collapsing
Girder						
Simple	237	.49	239	.63	7	.57
Continuous	17	.47	30	.33	7	.57
All	254	.49	269	.60	14	.57
Truss						
Simple	97	.18	238	.33	18	.67
Continuous	45	.11	141	.27	35	.31
All	142	.17	379	.31	53	.43
Masonry Arch	224	.47	422	.51	34	.76

From this data a conditional kill probability (P_{KH}) is derived for each size bomb and type of bridge, defined as the probability of collapse of at least one span, given a hit.

An examination of table A-I and figure A-1 indicates certain inconsistencies which may be due to the small sample size, improper identification of bomb size, or the fact that multiple hits are included in the data. One might expect a given bomb to do at least as much damage as a smaller one, and that a comparison between simple and continuous girder bridges should yield results similar to a comparison between simple and continuous truss bridges.

For girder bridges the vulnerability, given in table A-I, of continuous bridges is very nearly the same as for simple bridges except for 1000 pound bombs. Since these are indicated as being less effective than 500 pound bombs against continuous bridges, the data for the small sample size is suspect. Similarly the limited data for the 2000 pound bomb is also suspect, but may reflect the conjecture of reference (b) that bridges narrower than 24 feet do not permit the larger bomb to develop its full potential. In any case, it seems reasonable to assume that the vulnerabilities of simple and continuous girder bridges are essentially the same, and that the vulnerability for the 2000 pound bomb is at least as great as for the 1000 pound bomb.

[redacted]

[redacted]

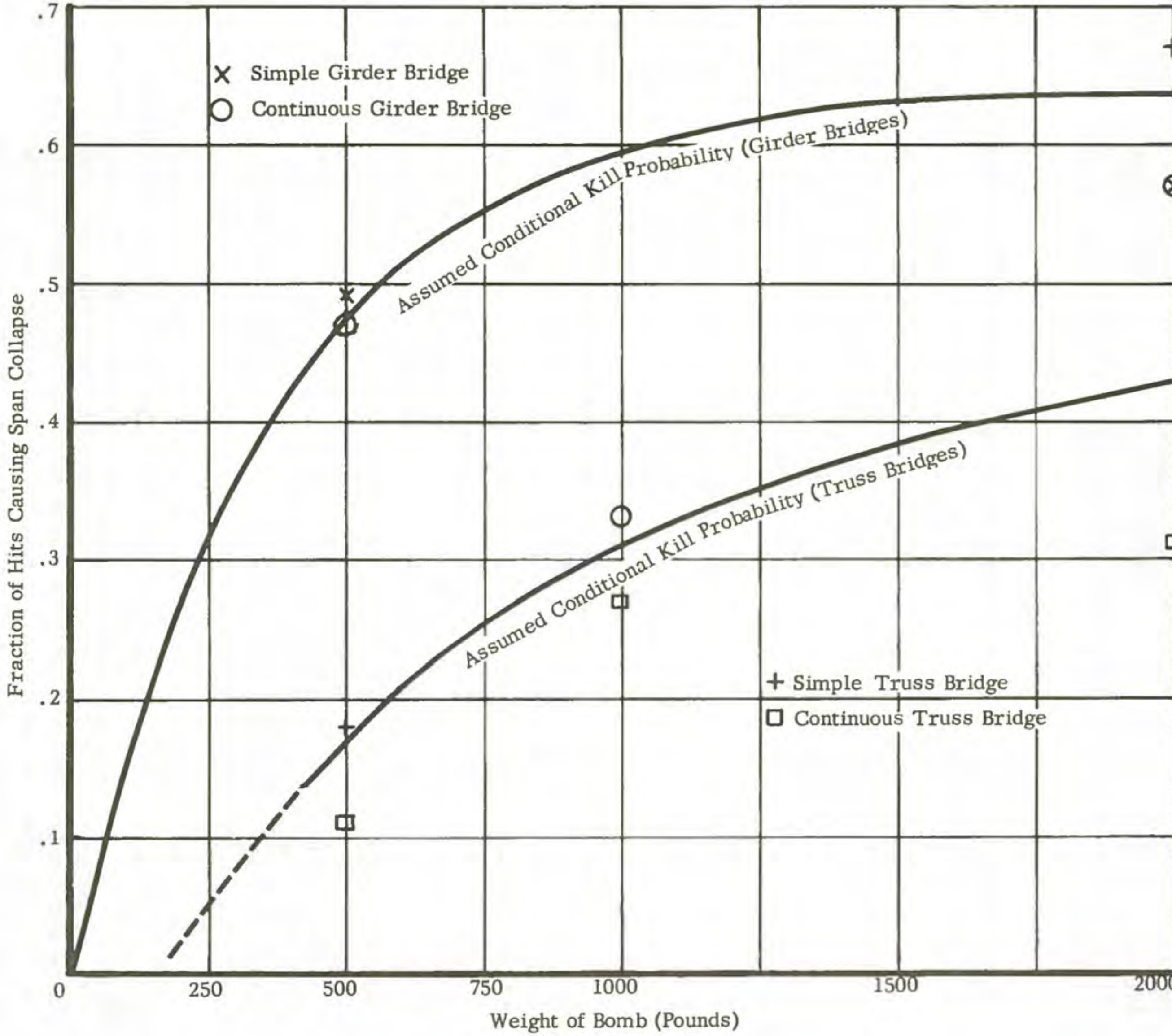

FIG. A-1

[redacted]

[redacted]

For truss bridges the preponderance of data is for the 500 pound and 1000 pound bombs. The continuous bridge appears to be somewhat less vulnerable than the simple bridge, and the truss bridge itself is much less vulnerable than the girder bridge. The large difference in apparent vulnerability of the simple and continuous truss bridges for the 2000 pound bomb appears unrealistic and may be due to the small sample size particularly for simple bridges.

Over-all, the masonry bridge appears to have approximately the same vulnerability as the girder bridge. It is not examined separately in this study, but it appears that the values derived for the girder bridge are essentially valid for use against masonry bridges.

The conditional kill probability for the 250 pound bomb was estimated by extrapolating downward from the other values. This indicates that the 250 pound bomb would be ineffective against truss bridges.

The terminal lethalities estimated in table A-II, are based on the above considerations. If additional investigation indicates other values for conditional kill probabilities, figure D-1 of appendix D may be used to determine sortie effectiveness. Because of the uncertainties and inconsistencies previously discussed, the values are rounded off to the nearest tenth.

TABLE A-II

ASSUMED CONDITIONAL KILL PROBABILITY (P_{KH})

Type of Bridge	Bomb Size			
	250 pound	500 pound	1000 pound	2000 pound
Girder	0.3	0.5	0.6	0.6
Truss	Ineffective	0.2	0.3	0.4

[redacted]

References: (a) Lehigh University Bomb Damage Analysis Final Report Volume II Part 2 Phase IV "Bridges" Unclassified 30 Jun 1949

(b) OSRD/NDRC Monthly Report EWT-3 "Effects of Weapons on Targets Volume 3" Unclassified 5 Jun 1945

APPENDIX B

APPENDIX B

A-1 BOMB SYSTEM

Summary

This appendix outlines the essential characteristics of the A-1 aircraft's bomb system which are useful for attack planning.

External Stores Stations

There are 15 external stores stations. These may be considered 2 separate semi-independent groups - Outer Wing Stations (12) and Inner Stations (3) - each with a separate release system and release switch. Both groups use the same intervalometer and arming circuits.

The outer stations consist of 12 Aero 14 bomb/rocket racks, 6 on each wing numbered consecutively from left to right. Each station can carry a maximum of 500 pounds. However, due to total weight and clearance limitations, not all stations can be used for certain loads (e.g., a maximum of 8 Mk 82 GP may be carried). The outer wings are each limited to a total load of 2120 pounds (1500 pounds if folded).

The 3 inner stations are called Left Inner, Right Inner, and Center or Fuselage. The 2 inner stations have Mk 51 bomb racks with Aero 1A adapters (Aero 65A in some versions) and a capacity of 3000 pounds each. The center station has an Aero 3A ejector rack with a capacity of 3600 pounds.

The inner stations can also mount external fuel tanks. Normal aircraft configuration is a 300-gallon tank on each left and right inner station, or one on the center station.

Bombing Equipment

Sight - A Mk 20 Mod 4, non-computing, illuminated gun sight is used as a bomb sight. It is adjustable in elevation only.

Fuze Arming - Bombs and rockets may be selectively armed - "Tail" or "Nose and Tail" - or released "Safe".

Interval - An interval selector is provided which allows releases in train at a rate of from 2 to 20 per second.

Method Selector - Bombs or rockets may be released either singly or in train. From the outer wing station they may be released individually or by pairs for either method.

Jettison - All stores (except rockets loaded on outer wing rocket launchers) may be jettisoned manually.

Station Selector - The inner stores are selected for either single or train releases by individual switches for each station. For the outer stations, a 12-position rotary switch is used to select the station to be released for single drops or the first station to be released in train. The switches in early aircraft are labeled from 1 to 12 in the order of release; later aircraft switches are labeled with the station numbers. When set on positions 1 through 6, stores are released individually; when on 7 through 12, pairs are released. As each station is released a ratchet allows the switch to move to the next position.

System Schematic

The inner and outer stations form 2 nearly independent systems. Each has its release switch, method selector switch, bomb-rocket switch, selector switches and jettison system. Both use the same arming circuit and either or both actuates the same interval generator. Both systems can release in train individually or simultaneously.

Figure B-1 is a simplified schematic of the bomb release system.

Operation

Outer Stations

The order of release from the outer wing stations is 1, 11, 3, 9, 5, 7, 12, 2, 10, 4, 8 and 6 for singles and 1-12, 2-11, 3-10, 4-9, 5-8 and 6-7 for pairs. Selector switch positions correspond to stores stations as follows:

Switch Position	Station
1	1
2	11
3	3
4	9
5	5
6	7
7	12-1
8	2-11
9	10-3
10	4-9
11	8-5
12	6-7

Single Release. With the Method Selector Switch set on "single", a release will be made (single or pair) each time the Outer Station Release Switch is closed. The setting of the Outer Station Selector Switch determines which station(s) will release. After each release the Station Selector Switch moves to the next position and the system is ready for subsequent releases.

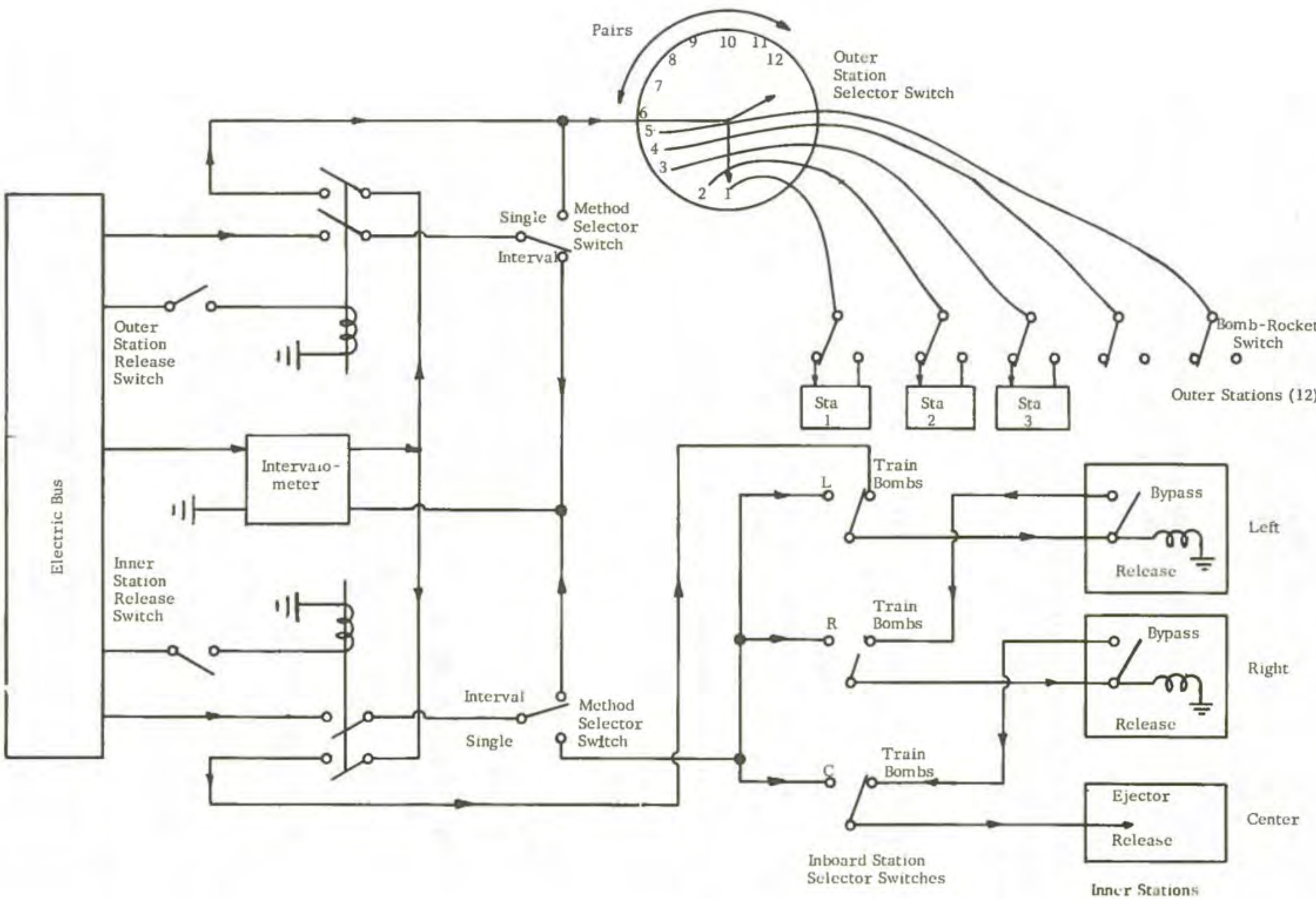

FIG. B-1: SIMPLIFIED SCHEMATIC OF A-1 BOMB RELEASE SYSTEM
(Rocket Release System Similar)

Train Release. With the Method Selector Switch set on Interval and the Outer Station Selector Switch at first release (single or pair) desired, releases will be made at the rate set on the Interval Selector Switch as long as the Outer Station Release Switch is closed or until final station has released. Some of the load may be released by initially positioning the Outer Station Selector Switch at a late pair setting.

Salvo Release. No true salvo is possible except by manual jettison. The closest approximation is a train release by pairs with the interval selected as 20 releases per second.

Bombs/Rockets. System operation is similar for either bombs or rockets except that for rocket pods an entire pod is fired on each release. The Bomb/Rocket Switch must be positioned for the type ordnance to be released.

Inner Stations

The order of release from the inner stations is left, right, center. Each station has an individual selector switch.

Single Release. With the Method Selector Switch set at "single" the station (or stations) selected with the Inboard Station Selector Switches will be released when the Inner Station Release Switch on control stick is closed.

Train Release. With the Method Selector Switch set at "Interval" and the Inboard Station Selector Switches set at "train Bombs" the stations selected will release at the rate set on the Interval Selector Switch when the Inner Station Release Switch is closed.

Salvo Release. With the Method Selector Switch set at "single" all stations selected by the Inboard Stations Selector Switches will salvo when the Inner Station Release Switch is closed.

Rocket Pods. Rocket pods on the left and/or right inner stations are fired when the Inner Station Release Switch is closed if the Inner Station Selector Switch is on "Rocket Packs" and the station is selected by its Inboard Station Selector Switch. If both stations are selected, both will ripple fire simultaneously.

Combined Inner and Outer Stations

Releases may be made from both Inner and Outer Stations singly and/or in train simultaneously if each system is set for the type release desired. There is no provision for a train release in which one system releases automatically immediately after the other has completed.

As shown in figure B-1, the left and right inner stations are provided with bypass switches so that an empty station would not affect the interval in train. However, the outer wing stations, which are not interconnected, are selected by the Outer Station Selector Switch, which is a simple step switch. Thus, an empty outer station would leave a gap in a train pattern. Figure B-2 shows some representative stick patterns possible with the A-1 system.

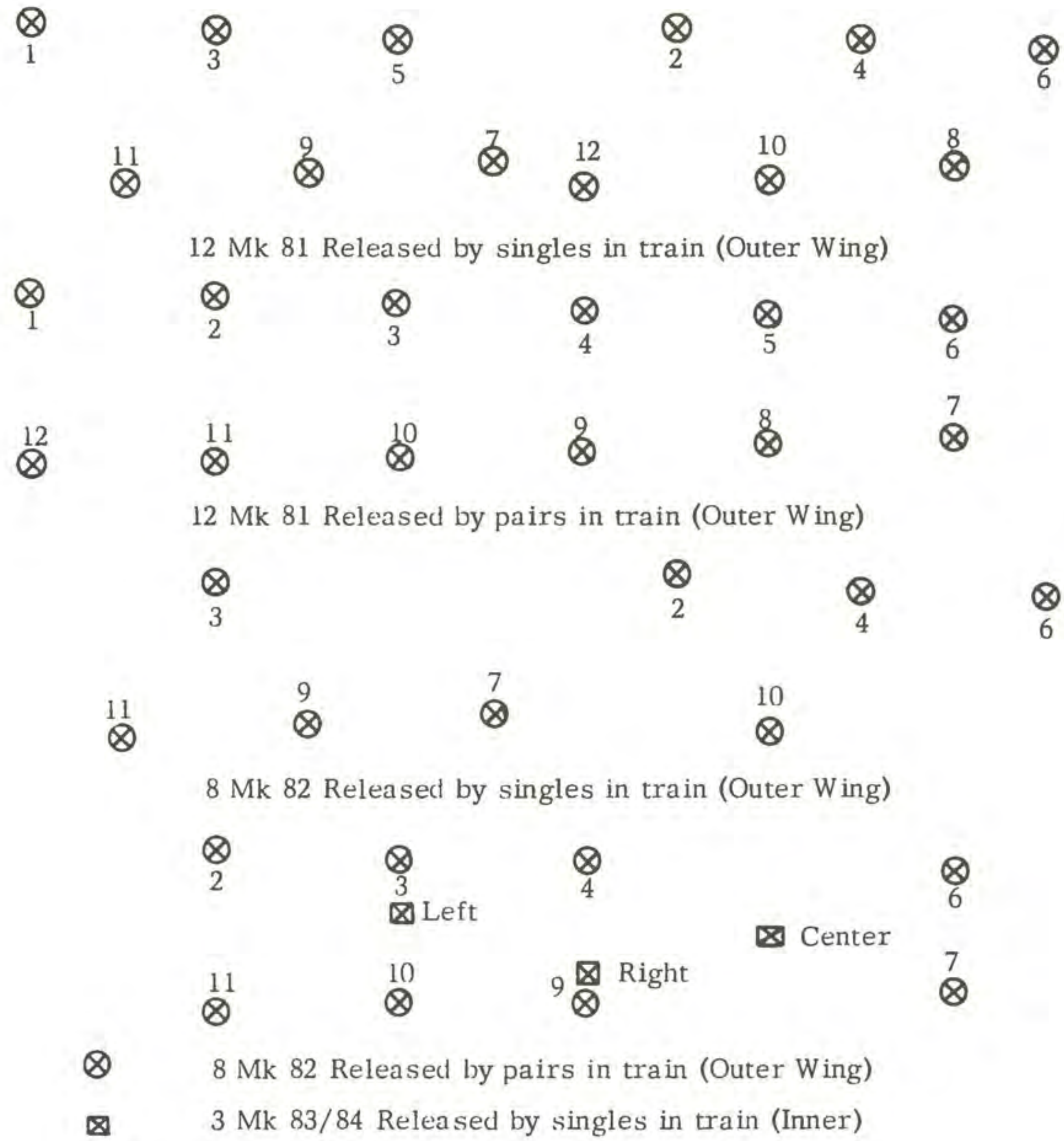

FIG. B-2: REPRESENTATIVE A-1 STICK PATTERNS
(Neglecting Ballistic Dispersion)

APPENDIX C

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APPENDIX C

SENSITIVITY TO CHANGES IN PARAMETERS

Sensitivity to Approach Angle

For the accuracy assumed (REP = 110, DEP = 70) and a stick length from 100-300 feet, effectiveness is relatively insensitive to approach angle. For stick length less than 100 or over 300 feet, maximum effectiveness is attained with attack near the bridge axis. For deflection errors about 1/5 range error, the advantage of an axis attack becomes marked, as shown in references (a) and (b). Figure C-1 shows the relation of approach angle to effectiveness. For a reasonably hard bridge ($P_{KH} = 0.2$) there is little change in effectiveness with change in approach angle, except for a salvo. The angle for maximum effectiveness is about 20 degrees but at this angle, which would be difficult to achieve in any event, less than 5 percent increase is realized. For a salvo release the effectiveness drops off markedly as the approach angle increases. For a relatively soft bridge ($P_{KH} = 0.5$), the effect of approach angle, as well as stick length, is more pronounced. For salvo release the effectiveness drops very rapidly as the approach angle increases — 90° is only about 75 percent as effective as 0°. For a 90 foot stick the effectiveness is maximum at about 20°, but only about 5 percent better than for 0°. For a 180 foot stick the optimum approach angle is greater (about 40°) and the increase in effectiveness is over 10 percent. However, since the effect of approach angle is small in most cases, the choice should be made on tactical considerations rather than effectiveness. A zero degree approach angle is normally recommended since it provides the simplest attack.

Sensitivity to Stick Length

For a zero degree approach angle the effectiveness of attack increases slightly for stick lengths up to about 100-200 feet, as shown in figure C-2, and then falls off as length is further increased. The effectiveness is essentially the same whether the bombs are dropped in pairs or singly, due to the spacing between wing racks. For attack along the bridge axis, bombs may be dropped in salvo with little loss in effectiveness. For sticks of 2 or 3 bombs the effectiveness is essentially the same as for a salvo. For attacks off the bridge axis the effect of stick length is most pronounced with the maximum effectiveness being for a stick of about 100-200 feet.

Sensitivity to Bridge Dimensions

Figure C-3 provides a rough guide for determining the number of sorties required for bridges of various dimensions. As to be expected, effectiveness increases with bridge size. However, because of inadequate data concerning kill probabilities against wide bridges, the values may be somewhat optimistic for bridges wider than 30 feet.

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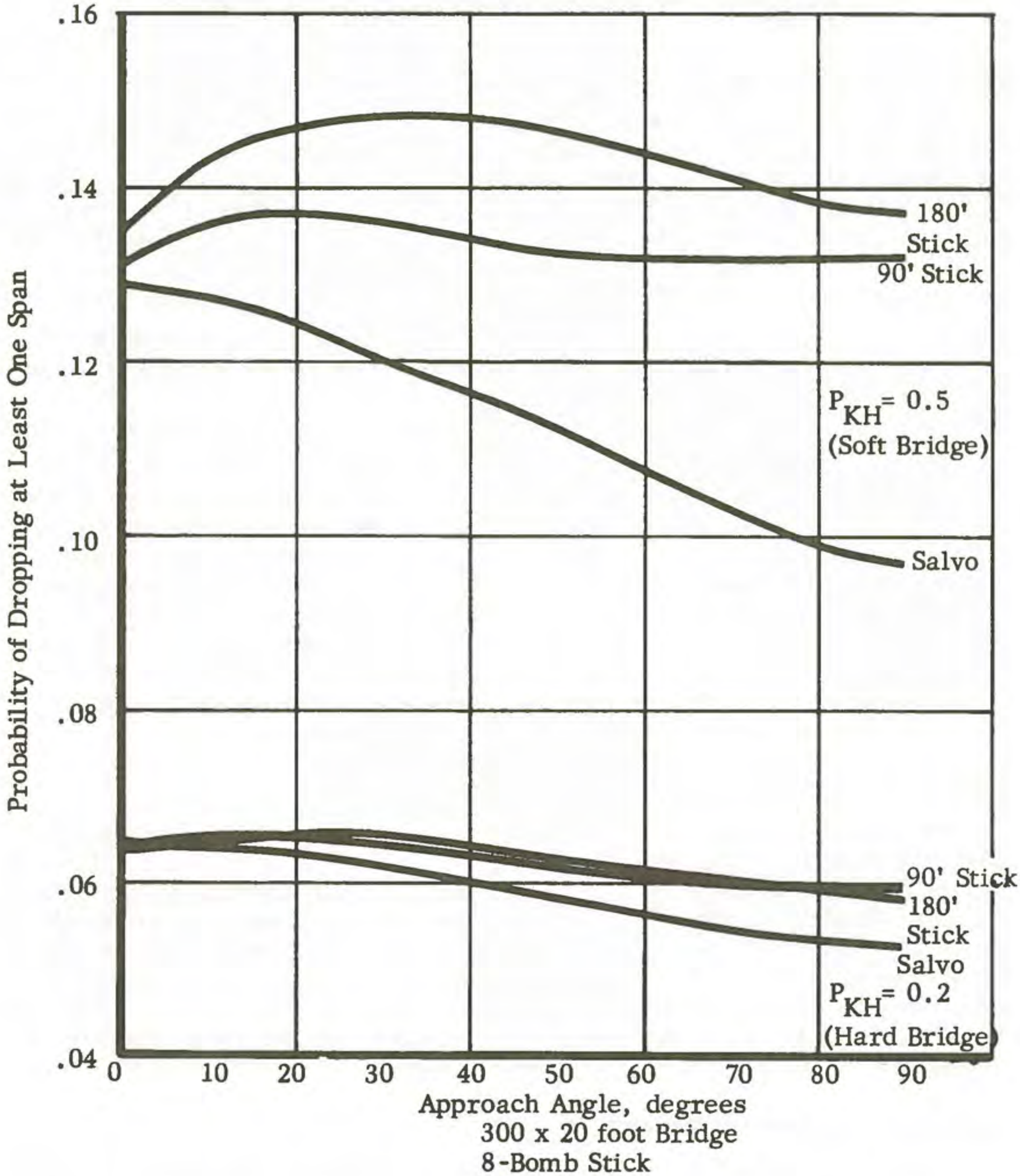

FIG. C-1: EFFECT OF APPROACH ANGLE ON EFFECTIVENESS

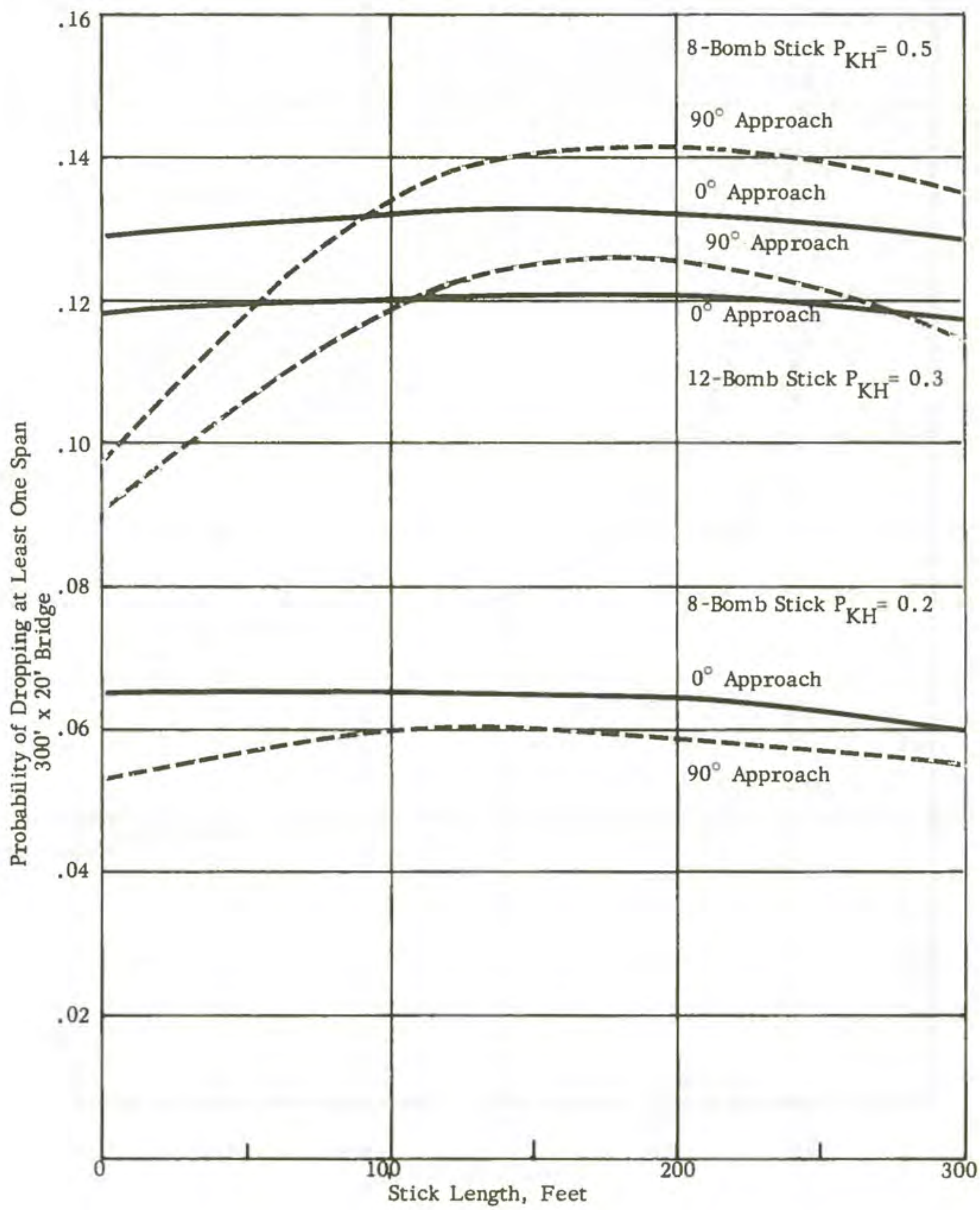

FIG. C-2: EFFECT OF STICK LENGTH ON EFFECTIVENESS

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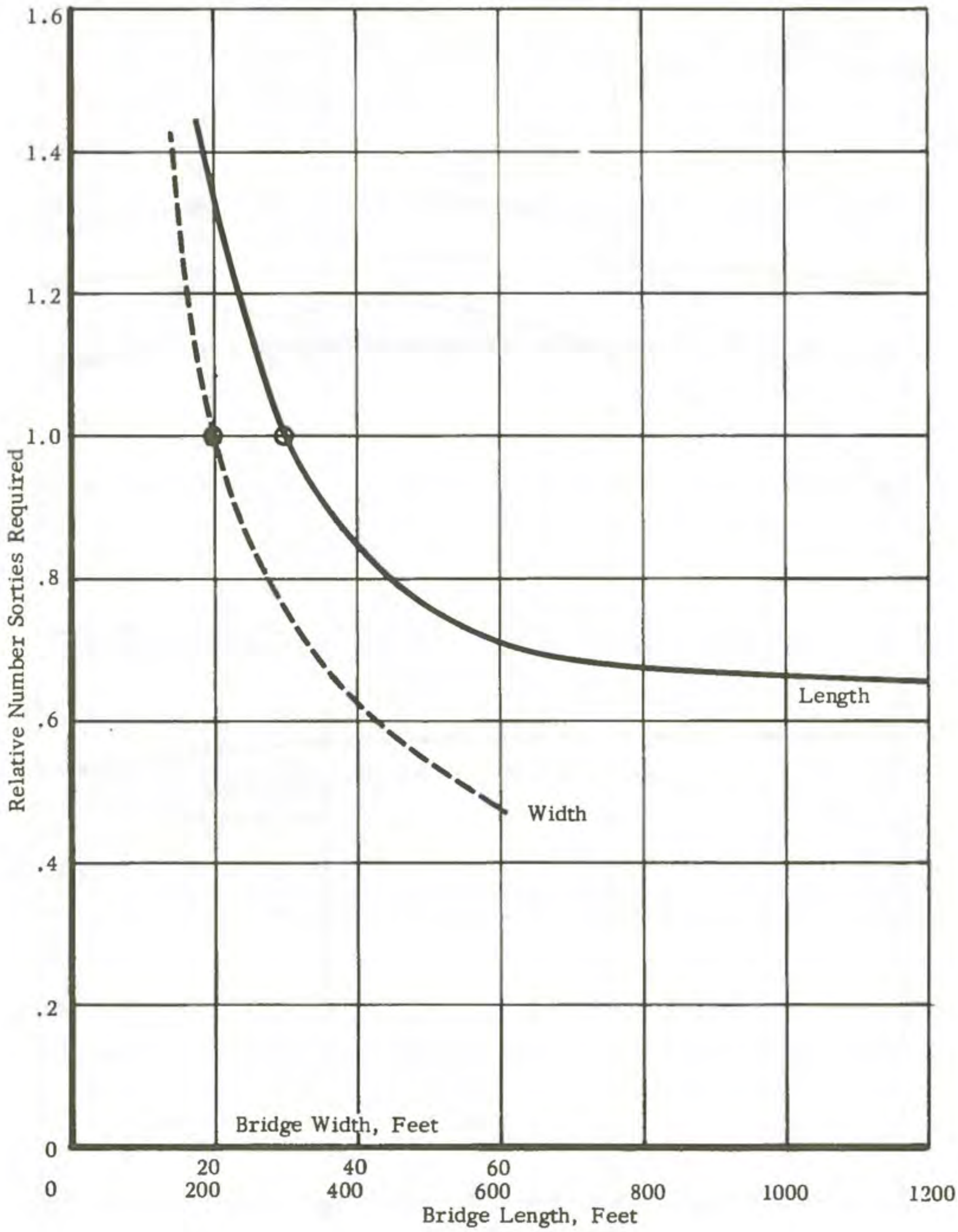

FIG. C-3: EFFECT OF BRIDGE SIZE ON EFFECTIVENESS

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Sensitivity to Delivery Accuracy

Although substantial uncertainty exists concerning expected combat accuracy, it appears that combat accuracy is significantly poorer than peacetime accuracy.

Statistics from World War II and Korea cannot be applied directly to present weapons and tactics. However, the combat degradation factors for combat accuracy versus peacetime training are significant. In general, it was found that the combat CEP was approximately 2.3 times that of peacetime exercises.

Considerations for determining the most likely values of combat accuracy are included in references (c) and (d). The values listed in these references are primarily for jets and will thus differ from those used in this study, which were taken from reference (e).

For maximum utility in sortie planning, a single value for "most likely" combat accuracy was used. Figure C-4 indicates the changes in effectiveness for various delivery accuracies. It is obvious that for an attack along the bridge axis deflection accuracy is most significant. The values of expected sorties listed in tables III and IV of the main body may be modified for various values of expected delivery accuracy as follows:

For DEP, feet	50	60	70	80	90	100	
Multiply sorties by	.7	.9	1.0	1.1	1.3	1.4	
For REP, feet	50	70	90	110	130	150	170
Multiply sorties by	.8	.8	.9	1.0	1.1	1.3	1.5

The sortie requirements listed in tables III and IV are based on a 30° glide delivery with an estimated combat accuracy of REP = 100 feet, DEP = 70 feet and CEP = 160 feet. In reference (c) it was shown that bombing errors could be represented by the following formulae:

$$REP = (A^2T^2 + B^2R^2/\mathrm{Sin}^2H)^{1/2} \quad \text{and}$$

$$DEP = (C^2T^2 + D^2R^2)^{1/2}$$

where T = time of fall
R = slant range at release
H = harp angle
A, B, C, & D = undetermined coefficients

A and C are coefficients related to time-of-fall errors which are basically due to ballistic dispersion and wind errors. Since ballistic dispersion is treated separately in the kill probability analysis, only wind error is considered

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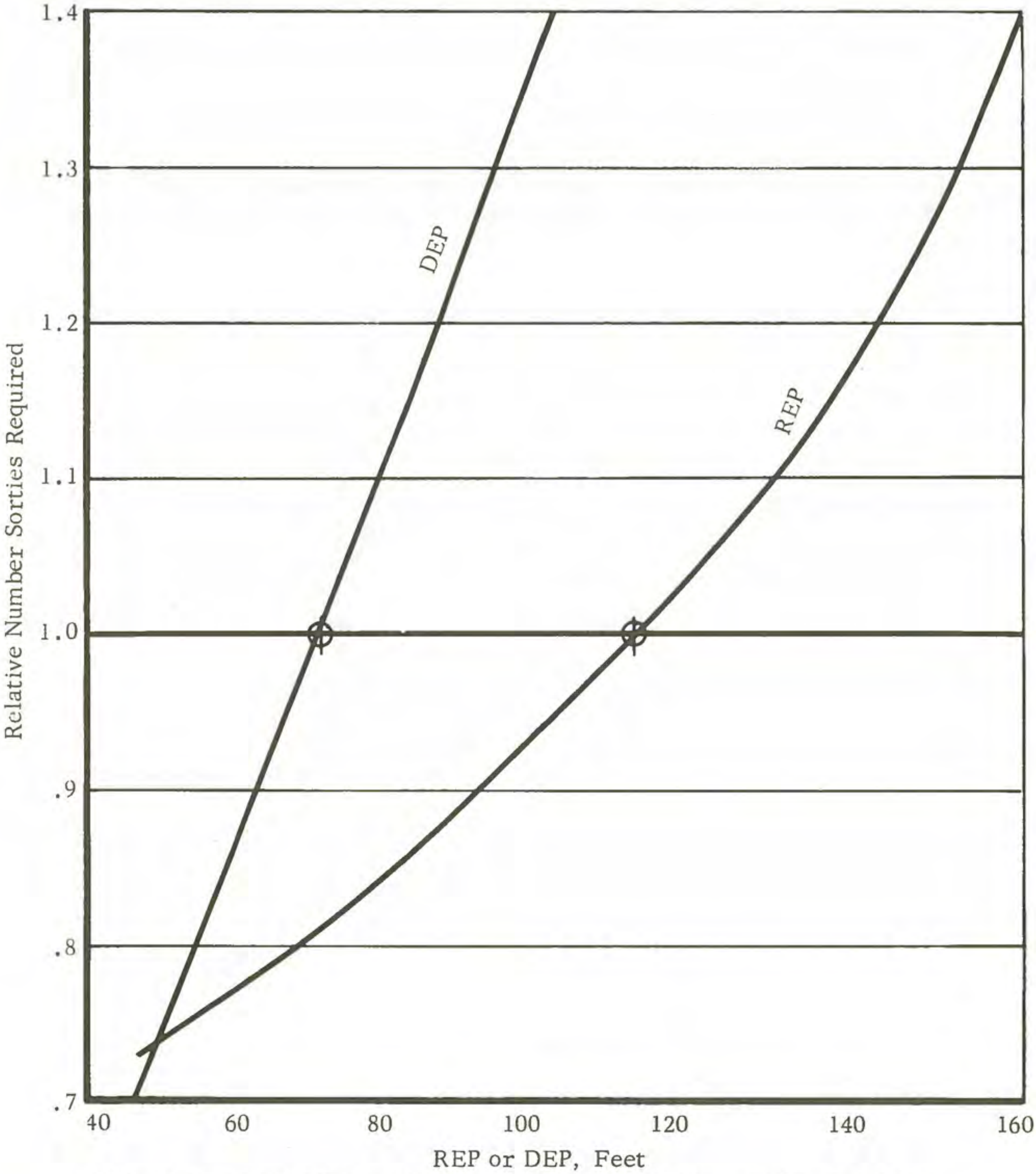

FIG. C-4: EFFECT OF DELIVERY ACCURACY ON EFFECTIVENESS

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and is assumed to be 8 feet/seconds (4.75 knots). Using the estimated combat accuracy of REP = 110 feet, DEP = 70 feet for a 30° glide delivery, the values for the other coefficients are determined as

$$B = 17.1 \text{ and } D = 14.6.$$

With all coefficients determined, the expected combat accuracy for the types of standard deliveries listed in reference (f) may be estimated as:

Delivery	Release Altitude, Feet	Speed, knots	Slant Range, Feet	Estimated Combat Accuracy CEP, Feet	REP, Feet	DEP, Feet
30° glide	2200	310	3500	160	110	70
50° glide	3200	340	3900	160	105	75
70° dive	2820	310	2950	110	65	60

From these values for estimated combat accuracy and figure C-4, the sorties required per kill in tables III and IV may be adjusted for delivery tactic as follows:

For 50° glide use tabulated values.
For 70° dive multiply tabulated value by 0.7.

Sensitivity to Errors in Ballistic Dispersion

Ballistic dispersion affects the kill probability in the same manner as delivery error. However, it is much smaller in magnitude. The ballistic dispersion assumed (15 feet in range and 10.5 feet in deflection) is only about one tenth of the expected delivery accuracy and thus minor deviations in the ballistic dispersion values would be negligible.

[redacted]

[redacted]

References:

(a) DePoy, P.E. "The Effectiveness of Stick Bombing Against Unitary Line and Rectangular Targets (U)" Presentation to Tenth Military Operations Research Symposium Confidential

(b) OEG Study 663 "Weapon Selection for A-4B/C (A4D-2/2N) Attacks Against Bridges (U)" Confidential Jul 1963

(c) OEG Study 659 "Predicted Combat Accuracy of Conventional Air-to-Surface Weapons (U)" Secret Nov 1963

(d) NAVWAG IRM 14 "Estimated Combat Accuracies of Bombing and Air-to-Surface Rocketry (U)" Confidential Oct 1962

(e) Joint Munitions Effectiveness Manual Delivery Accuracy Working Party Report #3 "Average Combat Accuracy of Conventional Weapons (U)" Confidential 11 Nov 1964

(f) CNO "Naval Air Training and Operating Procedures Standardization Manual A-1 H/J" Unclassified 17 Mar 1964

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APPENDIX D

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APPENDIX D

METHODS OE COMPUTATION

The expected number of sorties required to drop at least one span is the inverse of the single sortie kill probability. The single sortie kill probability was determined by using the IBM 7090 programs of references (a) and (b). These programs provide the expected probability that each bomb will drop a bridge span (the product of the probability of a bomb hit and the conditional kill probability given a hit). The individual probabilities are then combined to determine the total probability that a stick or salvo will drop at least one span. Independence between individual bomb hits is assumed (no cumulative damage effects). The program provides for the effects of:

- aiming error (accuracy)
- ballistic dispersion (assumed to have a standard deviation of 15 feet in range and 10.5 feet in deflection)
- individual weapon conditional kill probability (including weapon reliability)
- the spacing of bombs in the stick
- the distance between bomb racks on the aircraft
- the angle of approach relative to bridge axis
- bridge dimensions.

Plotting the results for the various cases considered provides the family of curves in figure D-1. This gives the probability of dropping at least one span with a stick of a single type bomb assuming a 300 x 20 foot bridge, a zero degree approach angle, expected accuracy of 110 feet REP/70 feet DEP and a stick length of 100-200 feet. The entry for P_{KH} is an index of bridge vulnerability as follows:

	P_{KH}	
Bomb	Girder Bridge	Truss Bridge
Mk 81 GP	.3	--
Mk 82 GP	.5	.2
Mk 83 GP	.6	.3
Mk 84 GP	.6	.4

The expected number of sorties required to collapse at least one span of the bridge is the reciprocal of the kill probability (P_K) found from the figure. The value may be modified for various bridge dimensions, expected accuracy, and assurance levels as previously discussed.

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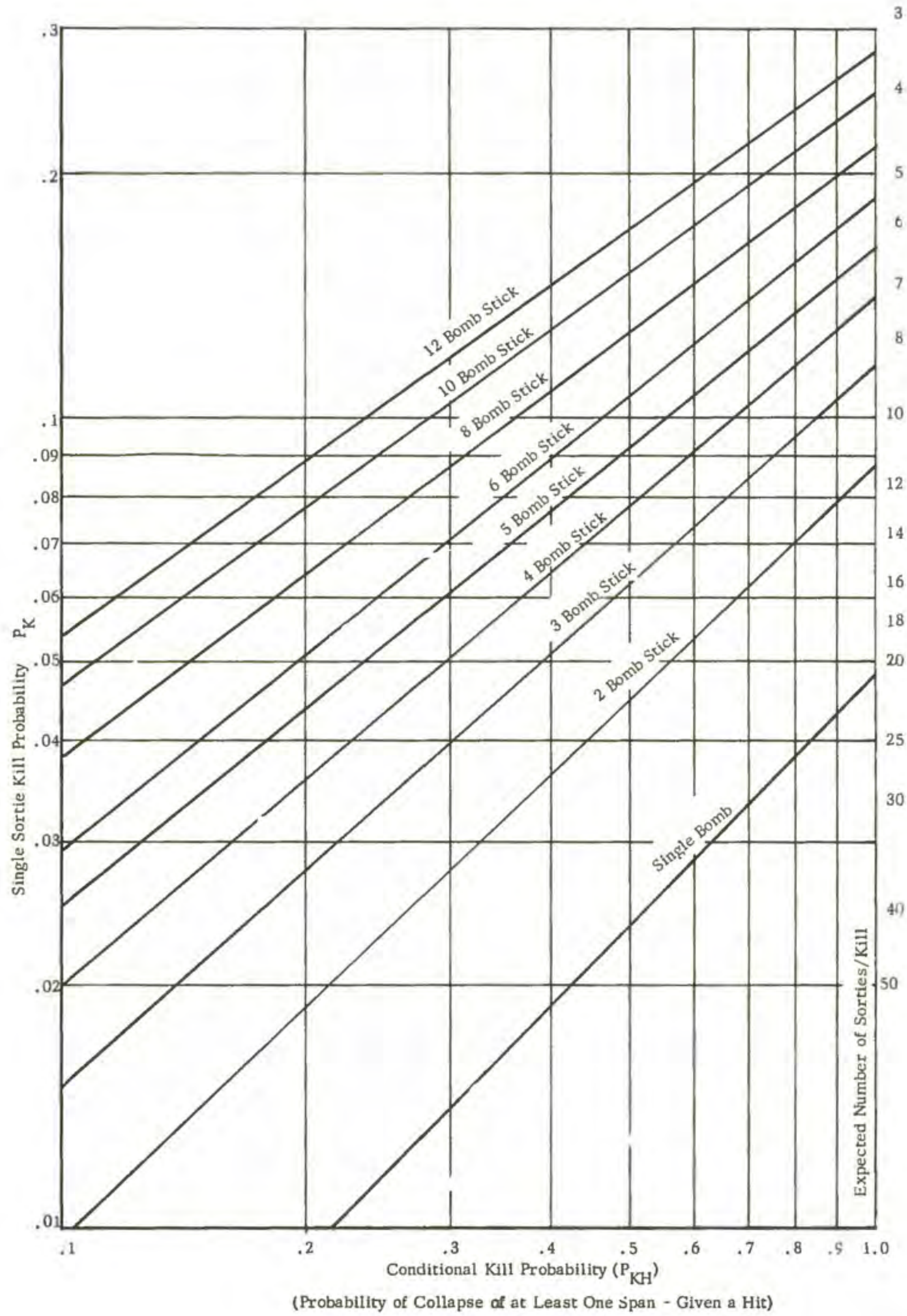

FIG. D-1: PROBABILITY OF COLLAPSING AT LEAST ONE SPAN OF A 300' x 20' BRIDGE BY A-1 STICK BOMBING

[redacted]

References: (a) NAVWAG NIRM-12 "Usage Manual for a Computer Program to Compute the Effectiveness of Groups of Weapons Against Rectangular and Line Targets" Unclassified 21 Aug 1962

(b) Operations Research and Mathematical Sciences Division, RC 6 "Weapon Pattern Effectiveness II CNA Computer Program 32-64P" Unclassified 3 Feb 1965

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13. ABSTRACT

This study determines the effectiveness of various A-1 aircraft payloads against bridges. The optimum load, regardless of bridge type, consists of eight-500 pound bombs plus additional ordnance as permitted by radius, loading time, and weight considerations. The effects of different intervalometer settings and approach angles are also analyzed: effectiveness is reduced if long intervalometer settings are used, but is insensitive to approach angle if the optimum setting is used. Data for adjusting the effectiveness estimates to reflect v: riations in bridge size and delivery accuracy are also provided.

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